

# The Enabling Technologies of the Geostationary Synthetic Aperture Microwave Sounder (GEO/SAMS)

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## ABSTRACT

The system architecture and two key enabling technologies required to implement a Geostationary Synthetic Aperture Microwave Sounder (GEO/SAMS), a millimeter-wave temperature/weather profiling instrument concept which can provide continuous, high spatial resolution observations from Geostationary orbit, are described. The baseline concept validation instrument is a Nadir pointed, fixed "Y-array" of 64 receiver elements, operating at 4 frequencies near 50 GHz. Adjacent element spacing of 1.9 cm and a 0.8 m equivalent aperture provide 300 Km surface spatial resolution. The architecture is fully scalable, allowing the number of receivers in the array to grow to provide whatever resolution is eventually desired. Follow-on instruments can provide better than 50 Km surface resolution, and can also incorporate moisture sounding at 183 GHz. The enabling technologies include advanced mm-wave GaAs or InP HEMT MMIC technology which allows the low-cost fabrication of many lightweight, miniaturized receiver elements, and utilization of 0.25 micron, Cu-interconnect CMOS to realize a highly integrated, real-time, parallel cross-correlator architecture. The entire concept validation system can be packaged in a system configuration that weighs no more than 58 Kg, consumes less than 185 watts continuous power, and provides scientifically meaningful data at a downlink rate not exceeding 750 Kbps continuous.

## INTRODUCTION

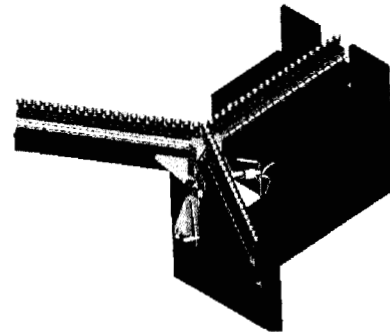
In order to provide high spatial resolution microwave imaging of the earth surface from geosynchronous altitude, large effective apertures are required. Practical limitations inherent in construction, deployment and scanning of real apertures that are several meters in diameter led the GEO/SAMS concept development team to propose a 2-D "thinned" aperture array as an effective alternative. GEO/SAMS instrument functional requirements and design constraints derived from basic science concepts and mission objectives specific to atmospheric temperature sounding [1], were used as the basis for the definition of a reference design. The resulting "proof-of-concept" instrument configuration meets all of these objectives while staying within target mass, power, volume, data rate and location constraints applicable to a variety of piggyback, Quick Ride or Free Flyer platforms. Augmentation of the reference GEO/SAMS instrument to include additional spectral bands (for vertical

resolution enhancement and to allow water vapor sounding), and higher instrument spatial resolution to fulfill the needs of future operational instruments, is readily achieved by the scalable nature of the instrument design.

## SYSTEM LAYOUT AND CONFIGURATION

A series of configuration trades to maximize flexibility led to the GEO/SAMS baseline, illustrated in Fig. 1. The GEO/SAMS functional block diagram is shown in Fig. 2. The "image" formed by the synthesized aperture, thinned array microwave sounder is produced by inverse FFT processing of a complex phase-amplitude map, which has been generated by comparing the phase of signals received simultaneously by each pair of receivers in the array.

The "front end" of the instrument consists of a Y-shaped array of identical receiving elements viewing the earth through a dedicated feed-horn, receiving microwave energy emitted primarily from the earth's atmosphere within a passband of 49 to 57 GHz. The nominal 3-dB beamwidth of each horn is a symmetric 20°, which produces a view of the entire earth disk plus some of the space background near the earth's limb. All the feedhorns in the array are aligned to receive the identical linear polarization. The array uses a single, frequency-selectable, phase stable LO, which, by way of a waveguide manifold, introduces a known amount of phase shift in the LO reference signal to each receiver. This allows the relative electrical phase of each receiver's output



**Figure 1. GEO/SAMS Configuration**

to be known. The received microwave energy signal from

Earth is mixed with the LO in each receiver element. Thus the phase difference between inputs to any pair of receivers in the Y-array can be measured. The outputs of each receiver are near-baseband, complex (I&Q) signals. These are conveyed to the analog processor via 128 equal-length sections of coax cable, which preserve the phase relationships of all outputs.

All receivers are also connected via a constant-phase waveguide manifold to a calibration noise source, allowing the relative phase of each receiver pair to be determined and tracked as instrument conditions vary on orbit. The calibration source phase offset per arm can be commanded on orbit during calibration, to allow characterization over a greater range of phase.

The image RMS noise for this array can be estimated from the physical parameters of the array and from simulations. The image noise calculations are summarized in Table 1. The basic Noise Equivalent Delta Temperature for the Array (NEDTA) follows from the work of Ruf [2], [3]. In addition, results from a simulation of the phase noise and the gain variations of the system between calibration intervals are included. This shows the advantage of being at GEO, where long integration times (~900 seconds) are achievable, versus LEO where only a few seconds of integration are possible.

## RECEIVER TECHNOLOGY

The GEO/SAMS receiver elements are a new development for this mission. The array requires a large number of identical receivers which must be packed together fairly tightly as dictated by the antenna feed spacing of approximately 1.9 cm. The receivers must be compact, reliable, and low-cost. MMIC technology, using GaAs or InP high electron-mobility transistors (HEMT) developed during the past few years, is highly suited to this application.

The new measurement technology of interferometric processing employed by GEO/SAMS levies design requirements different from conventional sounders on the GEO/SAMS receivers, including 1) Small erroneous correlations of noise in one receiver with the noise of another receiver will result in correlator offsets and errors in the resulting brightness temperature map, 2) Phase stability is very important in the system but the receiver phase stability requirements are somewhat mitigated by the noise calibration system, which calibrates the phase of the system rapidly (every few seconds if necessary), 3) Gain stability is less important in a correlation array because the receiver noises are uncorrelated and do not produce a large output proportional to gain as is the case of a single radiometer, and 4) Most radiometer sounders employ a single receiver; GEO/SAMS requires many. The need to obtain such a large number of receivers within a practical build time requires a

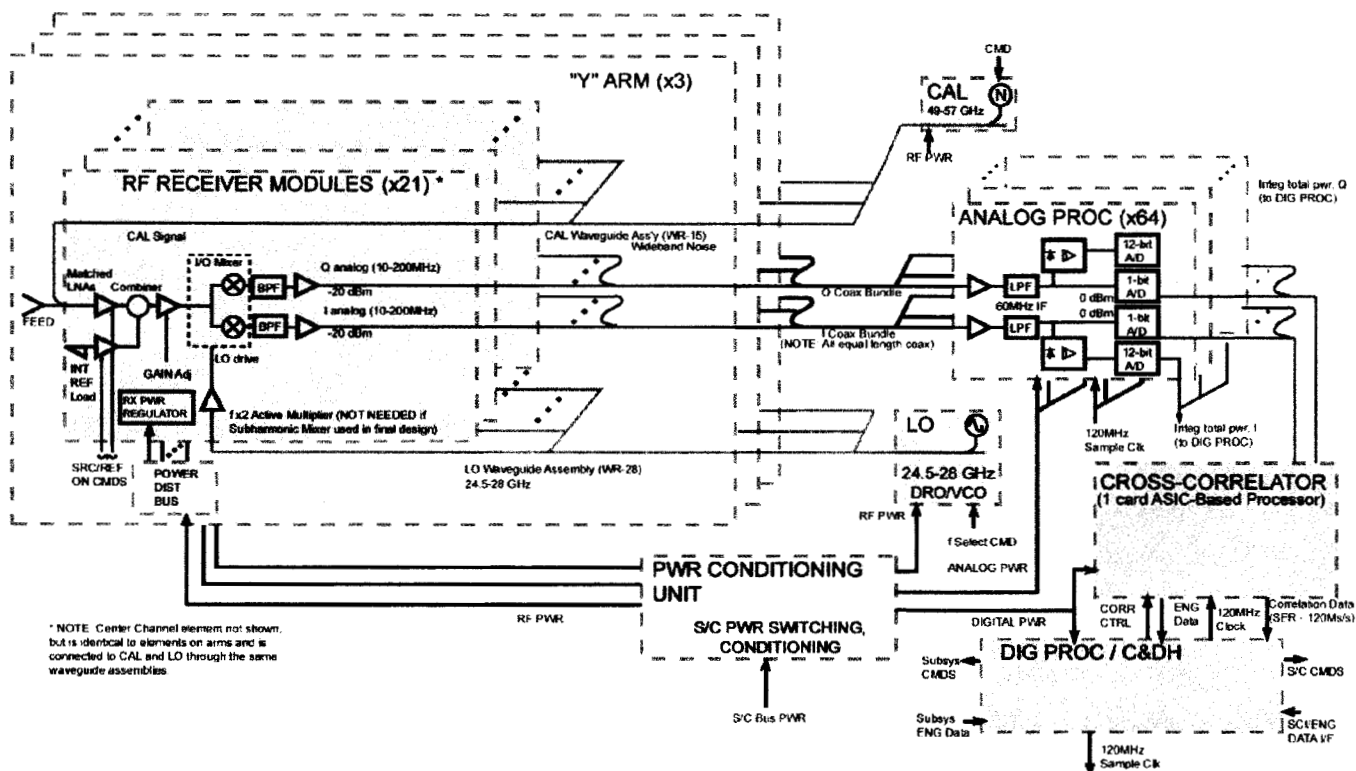


Figure 2. GEO/SAMS Functional Block Diagram

simple receiver design, allowing straightforward fabrication.

**Table 1. Estimated Total Image Noise (RMS NEDT) for the GEO/SAMS Baseline Instrument**

PARAMETER	SYMBOL	VALUE
Number of Independent Visibility Samples = $3*((21+2*0)+(21+2*1)+...+(21+2*21))/2$	$N_{vis}$	1612
Image Reconstruction Noise Multiplication Factor	NMF	80
Degradation Factor for 1-bit Correlator	DFC	1.57
System Noise Temperature = $T_{rev} + 290K$	$T_{sys}$	800
Correlator Bandwidth (MHz)	B	60
Integration Time per Frequency Band = $60*60/4$ (sec)	Tau	900
Number of Parallel Correlators	$N_{corr}$	2
NEDT for Array = $NMF*DFC*T_{sys}/(B*Tau*N_{corr})^{0.5}$ (K)	NEDTA	0.3
Image Noise due to Phase Noise of 0.3 deg (from simulations) (K)	$N_{ph}$	0.5
Gain Variation Noise => $\Delta G/G < 0.1\%$ (from simulations) (K)	$N_g$	0.1
TOTAL Image RMS Noise = $RSS(NEDTA + N_{ph} + N_g)$ (K)	NEDT	<0.6

## CORRELATOR TECHNOLOGY

The GEO/SAMS proof-of-design, 1-bit cross-correlator is a special purpose custom CMOS IC. It comprises a 32x32 array of cross-correlator cells which accumulate correlations between a set of digitized data inputs  $X_i$ , ( $i = 1-32$ ) and  $Y_j$ , ( $j = 1-32$ ). Each cell calculates the cross-correlation function between a signal  $X_i$  and  $Y_j$  by first performing a 1 bit multiplication of the two signals and then accumulating the products in one of two counters. Each cell is made of an Exclusive OR, two 32-bit accumulator/counters, and a 32-bit buffer/shift register. One of the accumulator/counters contains the integrated data from a calibration source and the other one the integrated data of earth radiation. The contents of accumulators can be read out from a correlator chip only after they have been transferred in parallel to the buffer/shift registers. This makes it possible to rapidly switch between two such sources without requiring a correspondingly rapid readout rate. The chip will calculate 1024-baseline correlations between the  $X_i$  and  $Y_j$  signals simultaneously, sampled at a maximum rate of 120 Ms/s.

Consequently, the 1-bit correlator chip can analyze noise signals with a maximum analog frequency of 60 MHz. It has 64% of the signal-to-noise ratio of a continuous correlator. At a clock frequency of 120 MHz the 32-bit counter in the correlator chip can accumulate, without overflowing, for approximately 35 seconds if inputs are fully correlated. The shortest integration time, determined by the interval of time required to read out the contents of the buffer/shift registers, is less than 10 nsec. Each correlator is provided with an 8-bit bus. The total read-out time per chip is estimated to be less than 10 msec. The cross-correlator can be designed using a standard processing cell library and a prototype can be developed using radiation-hard circuits for the 0.25 mm CMOS fabrication process (TSMC) available through the MOSIS fabrication facility.

## CONCLUSION

This paper presented a summary of the results of an instrument feasibility study conducted at JPL. The key enabling technologies and the unique system architecture of the GEO/SAMS have been presented. Additional funding to pursue development of the instrument is currently being sought.

## ACKNOWLEDGMENTS

This work represents early feasibility research, carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Funding was provided through NASA-HQ, New Millennium Program.

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